

The Effects of Power Supply Ripple on the Energy Doubler.

The purpose of this note is to calculate the effects of power supply ripple on the operation of the Energy Doubler. The primary effects are ripple fields which can distort the orbit especially during certain critical phases of the machine cycle, and heating via eddy current losses which eventually becomes a heat load on the cryogenic system.

This note is a follow-on of two previous notes: UPC # 31 developed a basic circuit for the observed eddy current losses in Doubler magnets. UPC # 37 developed the basic transmission line equations for long strings of Doubler dipoles, and specifically examined the characteristics of a long dipole string shorted at the ends in the time domain (Laplace transform) with typical power supply locations. The power supplies were considered to be ideal (ripple-free) voltage sources.

This note deals specifically with ripple voltages in the frequency domain. As will be seen later, the attenuation length of all important ripple currents is short compared to the length of the Energy Doubler (≈ 4 dipoles), and therefore the dipole string behaves very much like an infinitely long string (i.e. standing waves are not considered). Reference to figure 1 of UPC # 37 shows that the $\lambda = 5/2$ standing wave resonance is barely discernable at about 62 Hz. As the Q of the coil decreases roughly linearly with frequency (see UPC # 31 figure 4A and 4B), higher order resonances are significantly damped,

even without the use of damping resistors. As will be seen, the damping resistors play an important role, even if these standing wave modes were not present. A 20 ohm/dipole clamping resistor for example reduces the attenuation length of the 120 Hz ripple component by nearly a factor of 3, and similar reduces the peak ripple fields at 720 Hz by a similar factor, compared to a dipole string without damping resistors.

The basic model used for the dipole magnet is shown in figure 1. It differs from the earlier model used in UPC 37 in that all of the inductance is coupled to eddy current losses, hence causing the series inductance to match actual measurements better in the region above 1 kHz.

PDP-10 timeshare was used with complex number notation (in FORTRAN), as manipulation of complex impedances is quite straight forward. The basic equations used are (all numbers are complex and ω dependent):

$Z_0 = \sqrt{Z/Y}$ and $Y = \sqrt{Z \cdot Y}$ where Z and Y are the series impedance and shunt admittance per dipole (1 dipole = 1 unit length) the propagation velocity is given by $\omega/\text{Im}(\delta)$, and the attenuation length by $1/\text{Re}(\delta)$. In the case of the magnetic field, it was assumed that the current flowing through the inductance kL represented the magnetic field in the actual magnet.

In certain cases where direct comparison was possible, the results of these calculations were directly compared to the results of Cyber program SPICE.

the major shortcoming of SPICE is the lumped nature of the circuit used (typically 1 unit = 1 cell) which causes some discrepancy at higher frequencies where the cell length is a significant portion of a wavelength. At lower frequencies the agreement was quite good. One item which was demonstrated by SPICE is that about 90% of the ripple currents return via the cryostat and other parts of the ground circuit, and only about 10% by the Return bus. In the PDP-10 program the ground circuit and the Return bus were combined.

Ripple voltages and filter characteristics were obtained from Jerry Tool. Worst case ripple voltages and filter characteristics are:

<u>Frequency</u>	<u>V_{peak} w/o filter</u>	<u>V_{peak} with filter</u>
60 Hz	NONE	NONE
120	26 V	12.8 V
180	3.8 V	0.8 V
720	316 V	1.01 V
1440	156 V	0.66 V
2160	104 V	0.19 V
2880	80 V	0.08 V

The data are presented in a series of 9 tables with each variable tabulated as a function of 7 frequencies and 19 values of damping resistor. Although the tabulated value of the damping resistor is per dipole, in actuality it will be 4x this resistance and attached across a half-cell.

Table I. The magnitude of the transmission line impedance is tabulated vs frequency and damping resistor. The values for a $10\text{k}\Omega$ damping resistor are nearly the transmission line without any external damping. The "Dc" value is $\sqrt{L/C} = (.045\text{mH}/60\text{nF})^{1/2} = 866 \text{ ohms } \theta=0^\circ$. Note that for small damping resistors e.g. 10 ohms, the characteristic impedance is roughly proportional to $\sqrt{1/\omega}$. The power supply configuration is such that it sees twice the characteristic impedance, as it is in series with the coil bus (see UPC 37).

Table II the phase angle of the impedance. It is always slightly capacitive due to the real component of the series impedance. It is minimum at low frequencies and large damping resistor (-3.7°) and maximum at high frequencies and small damping resistor (-44.4°). The asymptotic limit is $\sqrt{-C} = -45^\circ$.

Table III. Phase rotation in degrees per dipole. This is the phase difference in the ripple current across each dipole magnet. The wavelength = $360^\circ / (\text{phase rotation per dipole})$.

Table IV Attenuation length (the number of dipoles to the 1/e point). Except for 60 cycles with a large damping resistor, the attenuation length is short compared to the Doubler length (774 dipoles) hence eliminating end effects. Arrows mark the approx location of the minimum value of attenuation length vs damping resistor value for each frequency. Although this should be considered in selecting the final value of the damping

resistor, the magnetic field transfer ratio and the dissipated power should also be considered. Note that for low damping resistor, high freq, att. length \times phase rot \approx 1 radia dipole

Table VI. Propagation velocity measured in # dipoles/sec. This becomes very frequency dependent (dispersive) for low values of damping resistor. The DC value is $\sqrt{1/LC} = 1.92 \times 10^4$ dipoles/sec

Table VI Magnetic field transfer ratio (Gauss/amp). The DC value of this number is 10 Gauss/amp. It is assumed in this calculation that the transfer ratio is $(10 \times \text{ripple current in inductance } KL) / \text{bus sup current}$. This can be compared to actual measurements (UPC* 99). Agreement is quite good up to 1 kHz for both cases (20 Ω damping resistor and no damping resistor) but for the no damping resistor case there is some divergence at higher frequencies, due in part to the physical location of eddy current losses relative to the coil (the cryostat, the major eddy current loss, is outside the coil and not between the coil and bore tube). The agreement is quite good at all frequencies for a 20 Ω damping resistor.

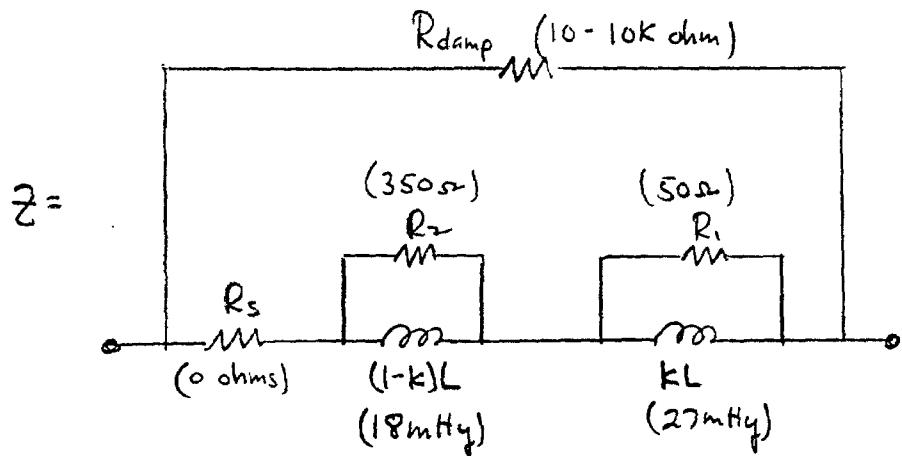
Table VII. The total ripple current flowing in the coil bus and the damping resistor, based on Jerry Tool's values for the ripple voltages presented above. Although the largest tabulated ripple currents are for low damping resistor values at 120 Hz, it should be observed that a large fraction of this current is shunted around the magnet by the damping resistor and therefore is not flowing in the coil bus.

Table VIII. Peak field (Gauss). These numbers are also based on Jerry Tools ripple voltage values. It is seen that in every case the damping resistor reduces the peak magnetic field (in the dipoles adjacent to the power supply). Using $B_{\text{inject}} = 6600$ Gauss the worst case $\Delta B/B$ is $\sim 8 \times 10^{-6}$ for a 20Ω damping resistor. Using $B_{\text{flat-top}} = 44\text{kG}$, $\Delta B/B$ is $\sim 1.2 \times 10^{-6}$. In both cases the subharmonics of 720 Hz, especially the 120 Hz component, seem to be the largest components.

Table IX Power (average watts) transmitted in each direction from power supply. This is the total power, including that dissipated in the damping resistors. This is dissipated over a length about $1/2$ attenuation length as tabulated in Table IV. The major power problem is the 120 Hz component (30mW) which is dissipated over a length of about 35 dipoles. It should be pointed out that the damping resistor is external to the cryogenic system and will in fact be attached across the shunt thyristors in the By-Pass bus i.e. across every half cell. The value of the resistor will be $4 \times$ the tabulated value i.e. a 20Ω /dipole damping resistor is equivalent to an 80Ω resistor across a half cell. The maximum power handling capacity (per dipole) is $\frac{1}{R} \left(L \frac{dI}{dt} \right)^2 \sim \frac{1}{20} \times (0.45 \times 400)^2 = 16$ watts/dipole for a 20Ω /dipole damping resistor.

Choice of damping resistor. The damping resistor choice should be based on not only the factors presented in this note (magnetic field ripple and attenuation length, power dissipation) but also the damping

of standing waves as per (UPC #37). In addition it also causes a field retardation relative to the power supply current much in the way the eddy currents do. The smaller a damping resistor is, the more serious the effects if it fails (opens up) or is inadvertently left out of a given half-cell. So, the best value is probably the largest acceptable value. The 120 Hz frequency component of ripple seems to be the biggest problem for magnetic fields and power dissipation. We note that although the peak magnetic field due to 120 Hz ripple continues to decrease for damping resistor values below $20\Omega/\text{dipole}$, the attenuation length reaches a minimum at this point. So the effectiveness of the damping resistor on minimizing orbit distortions is reduced below $20\Omega/\text{dipole}$. Furthermore, peak currents and power loss begin to rise significantly below $20\Omega/\text{dipole}$. As 20Ω seems to do a reasonable job of damping the standing waves (UPC #37) I would recommend a value of $20-25$ ohms/dipole ($80-100\Omega/\text{half cell}$). The resistor should be about 100 watt rated.



$$Y = \frac{1}{b} \quad C = 60\text{nF}$$

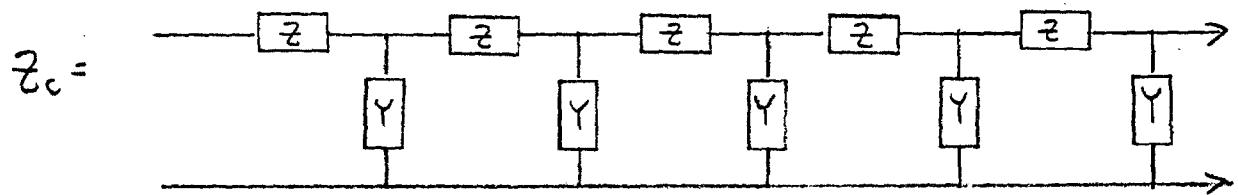


Fig 1 Basic Transmission Line Model with Damping Resistor

Table I Magnitude of characteristic impedance of dipole string vs freq and damp. Res.

DAMPING RESISTOR (OHMS)	FREQUENCY (HZ)						
	60.	120.	180.	720.	1440.	2160.	2880.
10.	600. ohms	445. ohms	387. ohms	187. ohms	133. ohms	109. ohms	95. ohms
15.	682.	525.	438.	226.	162.	133.	115.
20.	731.	583.	491.	258.	185.	152.	132.
30.	783.	659.	568.	308.	223.	184.	160.
50.	821.	734.	654.	377.	278.	230.	201.
70.	836.	769.	700.	424.	318.	265.	231.
100.	845.	794.	736.	471.	362.	304.	267.
150.	851.	812.	765.	519.	410.	349.	308.
200.	853.	820.	778.	547.	442.	380.	337.
300.	855.	828.	792.	578.	480.	420.	376.
500.	857.	833.	801.	604.	516.	461.	417.
700.	858.	835.	805.	615.	533.	481.	439.
1000.	858.	837.	809.	624.	546.	497.	457.
1500.	858.	838.	810.	631.	556.	511.	472.
2000.	859.	839.	811.	634.	562.	518.	480.
3000.	859.	839.	812.	638.	567.	525.	488.
5000.	859.	840.	813.	640.	571.	530.	495.
7000.	859.	840.	814.	641.	573.	533.	498.
10000.	859.	840.	814.	642.	574.	535.	501.

Table II Phase angle of characteristic impedance vs frequency and damping resistor

DAMPING RESISTOR (OHMS)	FREQUENCY (HZ)						
	60.	120.	180.	720.	1440.	2160.	2880.
10.	-30.5°	-37.1°	-39.5°	-43.0°	-43.8°	-44.2°	-44.4°
15.	-25.7	-33.9	-37.1	-42.0	-43.2	-43.7	-44.0
20.	-22.1	-31.1	-34.9	-41.1	-42.7	-43.4	-43.7
30.	-17.3	-26.7	-31.3	-39.5	-41.6	-42.6	-43.2
50.	-12.5	-21.1	-26.2	-36.6	-39.7	-41.2	-42.1
70.	-10.1	-17.8	-22.9	-34.3	-38.0	-40.0	-41.1
100.	-8.3	-15.0	-19.7	-31.6	-35.9	-38.4	-39.8
150.	-6.8	-12.5	-16.8	-28.4	-33.2	-36.2	-38.1
200.	-6.0	-11.2	-15.2	-26.3	-31.2	-34.5	-36.6
300.	-5.2	-9.8	-13.4	-23.7	-28.4	-32.0	-34.5
500.	-4.6	-8.7	-11.9	-21.1	-25.4	-29.1	-31.9
700.	-4.3	-8.2	-11.3	-19.9	-23.8	-27.5	-30.4
1000.	-4.1	-7.8	-10.8	-18.9	-22.4	-26.1	-29.1
1500.	-4.0	-7.5	-10.4	-18.1	-21.3	-24.8	-27.9
2000.	-3.9	-7.4	-10.2	-17.7	-20.7	-24.1	-27.2
3000.	-3.8	-7.2	-10.0	-17.2	-20.1	-23.4	-26.5
5000.	-3.7	-7.1	-9.8	-16.9	-19.6	-22.8	-25.8
7000.	-3.7	-7.0	-9.7	-16.7	-19.3	-22.6	-25.6
10000.	-3.7	-7.0	-9.7	-16.6	-19.2	-22.4	-25.4

Table III : Phase rotation (degrees/dipole) of ripple currents vs freq and damping resistor

DAMPING RESISTOR (OHMS)	FREQUENCY (HZ)						
	60.	120.	180.	720.	1440.	2160.	2880.
10.	0.7	0.9	1.1	2.1	3.0	3.7	4.2
15.	0.8	1.1	1.4	2.6	3.7	4.5	5.2
20.	0.9	1.3	1.6	3.0	4.2	5.2	5.9
30.	1.0	1.5	1.9	3.7	5.2	6.3	7.2
50.	1.0	1.8	2.3	4.7	6.7	8.1	9.3
70.	1.1	1.9	2.5	5.4	7.8	9.5	10.9
100.	1.1	2.0	2.7	6.2	9.1	11.1	12.7
150.	1.1	2.1	2.8	7.1	10.7	13.2	15.1
200.	1.1	2.1	2.9	7.6	11.8	14.6	16.8
300.	1.1	2.1	3.0	8.2	13.1	16.6	19.3
500.	1.1	2.1	3.0	8.8	14.5	18.8	22.0
700.	1.1	2.1	3.1	9.0	15.2	19.9	23.5
1000.	1.1	2.1	3.1	9.2	15.7	20.8	24.8
1500.	1.1	2.2	3.1	9.3	16.1	21.6	26.0
2000.	1.1	2.2	3.1	9.4	16.3	22.0	26.6
3000.	1.1	2.2	3.1	9.5	16.6	22.5	27.2
5000.	1.1	2.2	3.1	9.5	16.7	22.8	27.7
7000.	1.1	2.2	3.1	9.6	16.8	23.0	28.0
10000.	1.1	2.2	3.1	9.6	16.9	23.1	28.1

Table IV : Attenuation (#dipoles to 1/e) of ripple currents vs frequency and damp.res.

DAMPING RESISTOR (OHMS)	FREQUENCY (HZ)						
	60.	120.	180.	720.	1440.	2160.	2880.
10.	145.0	82.4	63.1	28.9	19.9	16.1	13.9
15.	149.7	75.6	55.8	24.3	16.6	13.4	11.5
20.	161.1	73.5	52.4	21.7	14.7	11.8	10.1
30.	190.1	74.8	49.9	18.8	12.4	9.9	8.4
50.	249.4	83.8	51.0	16.4	10.4	8.1	6.8
70.	301.3	94.0	54.1	15.4	9.4	7.2	6.1
100.	364.6	107.9	59.3	14.9	8.7	6.5	5.4
150.	441.8	126.0	66.6	14.9	8.2	6.0	4.8
200.	496.4	139.2	72.3	15.2	8.1	5.7	4.6
300.	568.2	157.0	80.2	15.9	8.1	5.5	4.3
500.	644.0	176.1	88.9	16.9	8.3	5.5	4.2
700.	683.4	186.2	93.6	17.6	8.6	5.5	4.1
1000.	716.5	194.7	97.6	18.2	8.8	5.6	4.1
1500.	744.6	202.0	101.0	18.8	9.1	5.7	4.2
2000.	759.5	205.8	103.8	19.2	9.3	5.8	4.2
3000.	775.1	209.9	104.7	19.5	9.5	5.9	4.2
5000.	788.1	213.2	106.3	19.8	9.6	6.0	4.3
7000.	793.7	214.7	107.0	20.0	9.7	6.0	4.3
10000.	793.1	215.8	107.5	20.1	9.8	6.0	4.3

Table V: Propagation velocity (dipoles/sec) of ripple currents vs frequency and damp. res.

DAMPING RESISTOR (OHMS)	FREQUENCY (HZ)						
	60.	120.	180.	720.	1440.	2160.	2880.
10.	3.2E+04	4.7E+04	5.9E+04	1.2E+05	1.7E+05	2.1E+05	2.5E+05
15.	2.7E+04	3.8E+04	4.8E+04	9.9E+04	1.4E+05	1.7E+05	2.0E+05
20.	2.5E+04	3.3E+04	4.1E+04	8.6E+04	1.2E+05	1.5E+05	1.7E+05
30.	2.2E+04	2.8E+04	3.4E+04	7.0E+04	1.0E+05	1.2E+05	1.4E+05
50.	2.1E+04	2.4E+04	2.8E+04	5.5E+04	7.8E+04	9.6E+04	1.1E+05
70.	2.0E+04	2.3E+04	2.6E+04	4.8E+04	6.6E+04	8.2E+04	9.6E+04
100.	2.0E+04	2.2E+04	2.4E+04	4.2E+04	5.7E+04	7.0E+04	8.1E+04
150.	2.0E+04	2.1E+04	2.3E+04	3.7E+04	4.9E+04	5.9E+04	6.9E+04
200.	2.0E+04	2.1E+04	2.2E+04	3.4E+04	4.4E+04	5.3E+04	6.2E+04
300.	2.0E+04	2.0E+04	2.2E+04	3.2E+04	3.9E+04	4.7E+04	5.4E+04
500.	2.0E+04	2.0E+04	2.1E+04	3.0E+04	3.6E+04	4.1E+04	4.7E+04
700.	1.9E+04	2.0E+04	2.1E+04	2.9E+04	3.4E+04	3.9E+04	4.4E+04
1000.	1.9E+04	2.0E+04	2.1E+04	2.8E+04	3.3E+04	3.7E+04	4.2E+04
1500.	1.9E+04	2.0E+04	2.1E+04	2.8E+04	3.2E+04	3.6E+04	4.0E+04
2000.	1.9E+04	2.0E+04	2.1E+04	2.8E+04	3.2E+04	3.5E+04	3.9E+04
3000.	1.9E+04	2.0E+04	2.1E+04	2.7E+04	3.1E+04	3.5E+04	3.8E+04
5000.	1.9E+04	2.0E+04	2.1E+04	2.7E+04	3.1E+04	3.4E+04	3.7E+04
7000.	1.9E+04	2.0E+04	2.1E+04	2.7E+04	3.1E+04	3.4E+04	3.7E+04
10000.	1.9E+04	2.0E+04	2.1E+04	2.7E+04	3.1E+04	3.4E+04	3.7E+04

Table VI: Magnetic field transfer ratio (Gauss/amp) vs frequency and damping resistor
(amps = amps in coil + amps in damp. res.)

DAMPING RESISTOR (OHMS)	FREQUENCY (HZ)						
	60.	120.	180.	720.	1440.	2160.	2880.
10.	4.9	2.7	1.8	0.4	0.2	0.1	0.1
15.	6.4	3.8	2.7	0.6	0.2	0.1	0.1
20.	7.4	4.8	3.4	0.8	0.3	0.2	0.1
30.	8.4	6.1	4.6	1.2	0.5	0.2	0.2
50.	9.2	7.7	6.2	1.8	0.7	0.4	0.2
70.	9.5	8.4	7.2	2.3	1.0	0.5	0.3
100.	9.7	8.9	7.9	2.9	1.3	0.7	0.5
150.	9.8	9.3	8.5	3.7	1.7	1.0	0.7
200.	9.8	9.4	8.8	4.1	2.0	1.2	0.8
300.	9.9	9.6	9.1	4.7	2.4	1.5	1.1
500.	9.9	9.6	9.3	5.2	2.8	1.9	1.3
700.	9.9	9.7	9.3	5.4	3.0	2.0	1.5
1000.	9.9	9.7	9.4	5.6	3.2	2.1	1.6
1500.	9.9	9.7	9.4	5.7	3.3	2.2	1.7
2000.	9.9	9.7	9.4	5.8	3.3	2.3	1.7
3000.	9.9	9.7	9.4	5.8	3.4	2.3	1.7
5000.	9.9	9.7	9.5	5.9	3.4	2.3	1.8
7000.	9.9	9.7	9.5	5.9	3.4	2.4	1.8
10000.	9.9	9.7	9.5	5.9	3.4	2.4	1.8

Table VII: Total ripple current (peak amps) vs frequency and damping resistor

DAMPING RESISTOR (OHMS)	FREQUENCY (HZ)						
	60.	120.	180.	720.	1440.	2160.	2880.
10.	0.0000	0.0143	0.0011	0.0027	0.0025	0.0009	0.0004
15.	0.0000	0.0121	0.0009	0.0022	0.0020	0.0007	0.0003
20.	0.0000	0.0109	0.0008	0.0020	0.0018	0.0006	0.0003
30.	0.0000	0.0097	0.0007	0.0016	0.0015	0.0005	0.0002
50.	0.0000	0.0087	0.0006	0.0013	0.0012	0.0004	0.0002
70.	0.0000	0.0083	0.0006	0.0012	0.0010	0.0004	0.0002
100.	0.0000	0.0080	0.0005	0.0011	0.0009	0.0003	0.0001
150.	0.0000	0.0078	0.0005	0.0010	0.0008	0.0003	0.0001
200.	0.0000	0.0078	0.0005	0.0009	0.0007	0.0002	0.0001
300.	0.0000	0.0077	0.0005	0.0009	0.0007	0.0002	0.0001
500.	0.0000	0.0076	0.0005	0.0008	0.0006	0.0002	0.0001
700.	0.0000	0.0076	0.0005	0.0008	0.0006	0.0002	0.0001
1000.	0.0000	0.0076	0.0005	0.0008	0.0006	0.0002	0.0001
1500.	0.0000	0.0076	0.0005	0.0008	0.0006	0.0002	0.0001
2000.	0.0000	0.0076	0.0005	0.0008	0.0006	0.0002	0.0001
3000.	0.0000	0.0076	0.0005	0.0008	0.0006	0.0002	0.0001
5000.	0.0000	0.0076	0.0005	0.0008	0.0006	0.0002	0.0001
7000.	0.0000	0.0076	0.0005	0.0008	0.0006	0.0002	0.0001
10000.	0.0000	0.0076	0.0005	0.0008	0.0006	0.0002	0.0001

* includes both coil current and damping resistor current

Table VIII: Peak field (Gauss) vs frequency and damping resistor

DAMPING RESISTOR (OHMS)	FREQUENCY (HZ)						
	60.	120.	180.	720.	1440.	2160.	2880.
10.	0.0E+00	3.9E-02	2.0E-03	1.1E-03	4.0E-04	7.3E-05	2.1E-05
15.	0.0E+00	4.6E-02	2.4E-03	1.4E-03	4.9E-04	8.9E-05	2.6E-05
20.	0.0E+00	5.2E-02	2.7E-03	1.6E-03	5.6E-04	1.0E-04	3.0E-05
30.	0.0E+00	5.9E-02	3.2E-03	1.9E-03	6.9E-04	1.3E-04	3.7E-05
50.	0.0E+00	6.7E-02	3.8E-03	2.4E-03	8.8E-04	1.6E-04	4.8E-05
70.	0.0E+00	7.0E-02	4.1E-03	2.8E-03	1.0E-03	1.9E-04	5.7E-05
100.	0.0E+00	7.1E-02	4.3E-03	3.2E-03	1.2E-03	2.3E-04	6.8E-05
150.	0.0E+00	7.3E-02	4.5E-03	3.6E-03	1.4E-03	2.7E-04	8.3E-05
200.	0.0E+00	7.3E-02	4.5E-03	3.8E-03	1.5E-03	3.0E-04	9.4E-05
300.	0.0E+00	7.4E-02	4.6E-03	4.1E-03	1.7E-03	3.4E-04	1.1E-04
500.	0.0E+00	7.4E-02	4.6E-03	4.3E-03	1.8E-03	3.8E-04	1.3E-04
700.	0.0E+00	7.4E-02	4.6E-03	4.4E-03	1.9E-03	3.9E-04	1.3E-04
1000.	0.0E+00	7.4E-02	4.6E-03	4.5E-03	1.9E-03	4.0E-04	1.4E-04
1500.	0.0E+00	7.4E-02	4.6E-03	4.6E-03	1.9E-03	4.1E-04	1.4E-04
2000.	0.0E+00	7.4E-02	4.6E-03	4.6E-03	1.9E-03	4.1E-04	1.4E-04
3000.	0.0E+00	7.4E-02	4.6E-03	4.6E-03	1.9E-03	4.1E-04	1.4E-04
5000.	0.0E+00	7.4E-02	4.6E-03	4.6E-03	2.0E-03	4.1E-04	1.4E-04
7000.	0.0E+00	7.4E-02	4.6E-03	4.6E-03	2.0E-03	4.1E-04	1.4E-04
10000.	0.0E+00	7.4E-02	4.6E-03	4.6E-03	2.0E-03	4.1E-04	1.4E-04

Table IX: Power* (watts) transmitted in each direction by power supply

DAMPING RESISTOR (OHMS)	FREQUENCY (HZ)						
	60.	120.	180.	720.	1440.	2160.	2880.
10.	0.0E+00	3.6E-02	1.7E-04	5.0E-04	2.9E-04	2.9E-05	5.8E-06
15.	0.0E+00	3.2E-02	1.5E-04	4.2E-04	2.4E-04	2.4E-05	4.8E-06
20.	0.0E+00	3.0E-02	1.3E-04	3.7E-04	2.1E-04	2.1E-05	4.2E-06
30.	0.0E+00	2.8E-02	1.2E-04	3.2E-04	1.8E-04	1.8E-05	3.5E-06
50.	0.0E+00	2.6E-02	1.1E-04	2.7E-04	1.5E-04	1.4E-05	2.8E-06
70.	0.0E+00	2.5E-02	1.0E-04	2.5E-04	1.3E-04	1.3E-05	2.5E-06
100.	0.0E+00	2.5E-02	1.0E-04	2.3E-04	1.2E-04	1.1E-05	2.2E-06
150.	0.0E+00	2.4E-02	1.0E-04	2.2E-04	1.1E-04	1.0E-05	2.0E-06
200.	0.0E+00	2.4E-02	9.9E-05	2.1E-04	1.0E-04	9.5E-06	1.8E-06
300.	0.0E+00	2.4E-02	9.8E-05	2.0E-04	9.8E-05	8.8E-06	1.7E-06
500.	0.0E+00	2.4E-02	9.7E-05	2.0E-04	9.4E-05	8.3E-06	1.6E-06
700.	0.0E+00	2.4E-02	9.7E-05	2.0E-04	9.2E-05	8.1E-06	1.5E-06
1000.	0.0E+00	2.4E-02	9.7E-05	1.9E-04	9.1E-05	7.9E-06	1.5E-06
1500.	0.0E+00	2.4E-02	9.7E-05	1.9E-04	9.0E-05	7.8E-06	1.4E-06
2000.	0.0E+00	2.4E-02	9.7E-05	1.9E-04	8.9E-05	7.7E-06	1.4E-06
3000.	0.0E+00	2.4E-02	9.6E-05	1.9E-04	8.9E-05	7.7E-06	1.4E-06
5000.	0.0E+00	2.4E-02	9.6E-05	1.9E-04	8.9E-05	7.6E-06	1.4E-06
7000.	0.0E+00	2.4E-02	9.6E-05	1.9E-04	8.8E-05	7.6E-06	1.4E-06
10000.	0.0E+00	2.4E-02	9.6E-05	1.9E-04	8.8E-05	7.6E-06	1.4E-06

* this represents $\frac{1}{2}$ the total ripple power output of each power supply which is dissipated in both the eddy current losses and the damping resistors over an attenuation length $\sim 50\%$ of value presented in Table IV.